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WATER PIPE
AND
SEWER DISCHARGE DIAGRAMS

T. C. EKIN
M. Inst. C.E. M. Inst. M.E. etc.

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WATER PIPE AND SEWER DISCHARGE DIAGRAMS

By

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Introduction.

THE formula of Ganguillet and Kutter, usually known as Kutter's formula, is, at the present time, considered one of the most reliable for finding the discharges of, and velocities in, water mains, because it takes into consideration the important element of "roughness," thereby giving truer and more accurate results than many of the older formulae which omitted this factor.

Curves of a similar nature to those now given were compiled in 1891 by Messrs. Taylor, but only for gradients up to 5 per 1,000. Gradients steeper than this are often required, and the author has calculated out a series of curves giving the discharges of pipes ranging from 3 to 48 inches in diameter when running full on gradients from 5·28 feet per mile, 1 in 1,000 or 1 per 1,000 up to 79·2 feet per mile, 1 in 66·6 or 15 per 1,000 which will be found in the four accompanying diagrams. Velocity curves have been added which it is hoped may be found of use. Each discharge curve is the result of twenty-two separate calculations and each velocity curve has been calculated for each point it cuts the discharge curve.

Kutter's formula in general form is :—

$$v=\left[\frac{a+\frac{l}{n}+\frac{m}{S}}{1+\left(a+\frac{m}{S}\right)\frac{n}{\sqrt{R}}}\right]\sqrt{RS}=c\sqrt{RS}$$

$$Q=60A\times v=60\ A\times c\sqrt{RS}$$

where

v=the mean velocity of water in feet per second.

R=the hydraulic mean depth or radius in feet. This value is obtained by dividing the area of the pipe in square feet by the length of the wetted perimeter or border in linear feet. For pipes running full, R is always one quarter the diameter of the pipe in feet.

S=the sine of the inclination=the fall of water surface (h) in any distance (l) divided by that distance or $\frac{h}{l}$.

n=the co-efficient of roughness depending on the nature of the internal surface of the pipe.

Q=the discharge of the pipe in cubic feet of water per minute.

A=the area of the pipe in square feet.

a, l and m are co-efficients derived from experiment and have the following values :—

197945

	In Metres.	In Feet.
$a=$	23	41·660475
$l=$	1	1·8113250
$m=$	0·00155	0·0028075

The metric co-efficients are the original ones given by Kutter. It may be useful to state that the co-efficients in feet are transformed from the metric ones by multiplying the latter by $\sqrt{3{\cdot}280899}=1{\cdot}811325$; the value 3·280899 being the number of feet in one metre.

Kutter's formula in British measurements is, therefore :—

$$v=\left[\frac{41{\cdot}660475+\frac{1{\cdot}811325}{n}+\frac{0{\cdot}0028075}{S}}{1+\left(41{\cdot}660475+\frac{0{\cdot}0028075}{S}\right)\times\frac{n}{\sqrt{R}}}\right]\times\sqrt{RS}=c\sqrt{RS}$$

where v, n, S, R have the meanings given above.

This formula is a troublesome one and tedious to work out, and many modifications have been suggested by engineers, amongst others Jackson, Moore, Hering and Flynn, with the view of saving labour, but in each case they require tables to solve them.

These modifications are :—

Jackson . . . $v=\frac{\sqrt{R}}{n}\times\frac{M+1{\cdot}811}{M+\sqrt{R}}\times\sqrt{RS}$

Moore . . . $v=\frac{NR}{\sqrt{R}+D}$

Hering . . . $v=\frac{y}{1+\frac{x}{\sqrt{R}}}\times\sqrt{RS}$

Flynn . . . $v=\frac{K}{1+\frac{x}{\sqrt{R}}}\times\sqrt{RS}$

The letters in these formulae have the significance attached to them by their respective authors to whose published works the reader is referred.

The modified formulae of Hering and Flynn are identical in form and the last-named one has been adopted by the author in working out the discharge and velocity curves on the accompanying diagrams.

In the formula

$$v=\left[\frac{K}{1+\frac{x}{\sqrt{R}}}\right]\sqrt{RS}=c\sqrt{RS}$$

where

$$K=41{\cdot}660475+\frac{1{\cdot}811325}{n}+\frac{0{\cdot}0028075}{0{\cdot}001}$$

$$x=41{\cdot}660475+\frac{0{\cdot}0028075}{0{\cdot}001}\times n$$

the following are the values of K and x with their logarithms for the different values of n, the co-efficient of roughness :—

n.	K.	Log. K.	x.	Log. x.
·010	225·600	2·3533391	·444680	$\bar{1}$·6480476
·011	209·134	2·3204246	·489147	1·6894394
·012	195·412	2·2909512	·533615	1·7272281
·013	183·801	2·2643479	·578083	$\bar{1}$·7619902
·014	173·848	2·2401697	·622551	1·7941749
·015	165·230	2·2180889	·667018	1·8241375
·016	157·676	2·1977656	·711486	1·8521664
·017	151·016	2·1790230	·755955	1·8784960

On referring to the original form of the formula in British measurements, it will be observed that the fractional expression c in square brackets contains three variable quantities, namely n, the co-efficient of roughness, S, the sine of the inclination and $\sqrt{R}$, the square root of the hydraulic mean depth or radius in feet. For any set of curves drawn for one particular co-efficient of roughness, n is a constant quantity, S varies according to the gradient and $\sqrt{R}$ varies according to the diameter of the pipe. But it has been found, and can easily be proved by calculation, that the value of the fractional expression c in square brackets, except for $\sqrt{R}$, is practically constant for all values of S with a steeper gradient than 1 in 1,000.

The diagrams which are the subject of this publication have, therefore, been calculated out by Flynn's modified formula as given above, with the co-efficients n=0·013 and S=0·001 taken as constant throughout the series of curves, but $\sqrt{R}$ varying with each diameter of pipe.

The curves are drawn for a co-efficient of roughness of 0·013. This co-efficient is applicable for most practical work under ordinary conditions, but there are a large number of cases in which pipes calculated with this co-efficient give results either too large or too small. With the view of making these diagrams apply to several co-efficients of roughness, the author has calculated out a series of constants which will be found in Table I. These constants are based on the co-efficient of roughness n=0·013 being taken as the standard, i.e. 1·0000 and this table alone will show the very marked effect the co-efficient of roughness has on the discharge and how necessary it is to decide upon the proper one in order to get the true discharge of the pipe. For instance, from this table, it will be seen that a 3-in. pipe with a co-efficient of 0·010 gives a discharge of a little over 46 per cent. greater than one with a co-efficient of 0·013. If the co-efficient is taken at 0·017, this pipe will only give a discharge of about 67½ per cent. of that which it would give if the co-efficient were 0·013.

At the other end of the Table it will be noticed that a 48-in. pipe with a co-efficient

*

of 0·010 will give an increased discharge of 34 per cent. over the standard, and a discharge of only about 74 per cent. of a similar sized pipe with a co-efficient of 0·013.

As to the proper co-efficient of roughness to allow for, it is one which in all cases must be left to the individual judgment of the engineer and will depend to a large extent upon the class of pipe used, the manner in which it is laid, and on the nature of the water. If the water is impure or liable to encrust, it may, in the course of time, reduce the discharge capacity of the pipe.

The following table of co-efficients of roughness n as compiled from Kutter, Jackson and Hering by Flynn, will give a general idea as to the one to be selected :—

n=·010 Plaster in pure cement ; glazed, coated or enamelled stoneware and iron pipes ; glazed surfaces of every sort in perfect order.

n=·011 Plaster in cement with one-third sand in good condition ; also for iron, cement and terra-cotta pipes, well jointed and in best order.

n=·012 Intermediate value.

n=·013 Ashlar and well-laid brickwork ; ordinary metal ; earthenware and stoneware pipe in good condition, but not new ; cement and terra-cotta pipe not well jointed nor in perfect order ; plaster in imperfect or inferior condition ; and generally, the materials mentioned with n=·010, when in imperfect or inferior condition.

n=·014 Intermediate value.

n=·015 Second-class or rough-faced brickwork ; well dressed stonework ; foul and slightly tuberculated iron ; cement and terra-cotta pipes with imperfect joints and in bad order.

n=·016 Intermediate value.

n=·017 Brickwork, ashlar, and stoneware in an inferior condition ; tuberculated iron pipes ; and, generally, the materials mentioned with n=·013 when in bad order and condition.

A small table published by A. Wollheim, A.M.I.C.E., gives, in a general form, the average values of n under various conditions and will be seen to include all the co-efficients given in Table I.

TABLE OF AVERAGE VALUES OF n.

Material of Pipe.	Condition of Surface (Internal).			
	Perfect.	Good.	Fair.	Bad.
	$n=$	$n=$	$n=$	$n=$
Glazed stoneware	·010	·011	·013	·015
Brickwork ordinary	·012	·013	·015	·017
Brickwork, glazed	·011	·012	·013	·014
Rendering, cement mortar	·011	·012	·013	·015
Rendering, neat cement	·010	·011	·012	·013
Ashlar, dressed	·013	·014	·015	·017
Iron (cast) uncoated	·012	·013	·014	·015
Iron (wrought) and steel	·011	·012	·013	·014

The diagrams consist of four sheets giving the discharges of every inch diameter of pipe from 3 in. to 48 in. when running full and with a co-efficient of roughness $n=0{\cdot}013$.

At both sides of each sheet is given the hydraulic gradient expressed in the three following ways:—

Feet per mile.

One in N.

Feet per 1,000.

It may here be remarked that the last named scale giving the inclination per 1,000 also expresses the head of water in feet required to overcome the friction in the pipes per 1,000 ft. in length when discharging the given quantities of water shown in the diagrams.

The velocity curves are drawn for every quarter foot per second, this being thought to be sufficiently accurate for all practical purposes. Should the discharge of any pipe be found in between these velocity curves, an approximation by the eye will be sufficiently near.

Should pipes be laid at greater or less gradients than those contained in the diagrams, it is only necessary to remember that the discharge varies as the square root of the fall. Thus, in order to find the discharge of any pipe having a fall greater than that given in the diagrams, we must divide the fall by 4, 9, 16 or 25 to bring it within the diagrams, and multiply the discharge of the pipe on the reduced fall by the square root of the number by which the fall was divided. If, on the other hand, the gradient is less, we must multiply the fall by 4, 9, 16 or 25 to bring it within the diagrams, and divide the discharge of the pipe on the increased fall by the square root of the number by which the fall was multiplied.

It will be observed that the discharges are given in cubic feet per minute, as

being the generally accepted method of stating the discharge of water pipes, but as several engineers still use and prefer gallons per minute, the author has added two tables, giving in No. II the equivalents of cubic feet in gallons per minute, hour and day, and in No. III the gallons equivalent to cubic feet per minute, hour and day, which it is hoped may be of service to those using the diagrams.

Examples

In water supply problems, the information generally required takes the form of one of the four following cases, viz. :—

Required.	Data given.
1. Discharge	Diameter and gradient.
2. Diameter	Discharge and gradient.
3. Gradient	Diameter and discharge.
4. Velocity	Discharge, diameter and gradient.

Ex. 1. What will be the discharge of an 18-in. diameter main 5,550 ft. in length with an available head of 30 ft. ? The hydraulic gradient can be expressed in one of the three following ways, viz. $\frac{5,280 \times 30}{5,550} = 28{\cdot}5$ ft. per mile, $\frac{5,550}{30} = 185$ or 1 in 185, or $\frac{30 \times 1,000}{5,550} = 5{\cdot}405$ ft. per 1,000.

Refer to diagram No. 2 and in the vertical columns at the ends of each diagram giving the hydraulic gradient expressed in any one of the above three methods, find the gradient and cast the eye along the line horizontally until it cuts the 18-in. pipe curve. The vertical line passing through this point gives 450 cub. ft. per minute, which is the discharge of an 18-in. pipe under the given conditions. The velocity is shown to be 4·25 ft. per second, and as the hydraulic gradient when expressed in "feet per 1,000" likewise gives the head of water in feet required to overcome the friction in the pipes per 1,000 ft. in length, we have only to multiply the length of the pipe in thousands of feet, viz. 5·55 by the hydraulic gradient in feet, per 1,000, viz. 5·405, when we get 30 ft. as the total head of water in feet required to overcome the friction in the pipe. This last problem has only been worked out as an example as the question gave the available head. Had the figure of the available head been omitted and only the hydraulic gradient given, it might have been necessary to know how to calculate the total head of water required to overcome the friction in the pipe.

Ex. 2. What would be the discharge of an 18-in. diameter pipe 55,550 ft. long, with an available head of 30 ft. ? The hydraulic gradient is $\frac{5,280 \times 30}{55,550} = 2{\cdot}85$ ft. per

mile, $\frac{55,550}{30}=1,850$ or 1 in 1850, or $\frac{30\times1,000}{55,550}=0{\cdot}5405$ ft. per 1,000. This gradient is not given in the diagrams, but as the discharge varies as the square root of the fall, we have only to multiply the hydraulic gradient by such number (preferably one whose square root is a whole number) as will increase it sufficiently to bring it within the diagram. If, for example, we multiply the hydraulic gradient by 16, we get $0{\cdot}54\times16=8{\cdot}64$ ft. per 1,000. On referring to diagram No. 2, we find that the horizontal line of 8·64 ft. per 1,000 cuts the 18-in. pipe curve on the vertical line 570 cub. ft. per minute. Dividing this discharge by 4 (the square root of 16), we get 142 cub. ft. as the true discharge.

Ex. 3. What diameter of pipe is required to discharge 3,000 cub. ft. of water per minute through a main 10,000 feet long with an available head of 64 ft. 6 in.? In this case the hydraulic gradient is 34 ft. per mile, 1 in 155 or 6·45 per 1,000. On referring to diagram No. 3 and at the point where the vertical line of 3,000 cub. ft. per minute cuts the horizontal line of the hydraulic gradient, it will be seen that the nearest size of pipe is 35 in., and the velocity of water 7·5 ft. per second.

Ex. 4. What diameter of pipe is required to discharge 2,600 cub. ft. of water per minute through a main 2,500 ft. long and available head of 50 ft.? The hydraulic gradient is $\frac{5,280\times50}{2,500}=105{\cdot}6$ ft. per mile, $\frac{2,500}{50}=1$ in 50, or $\frac{50\times1,000}{2,500}=20$ per 1,000. As the hydraulic gradient is greater than those given in the diagrams, we must divide it by 4 and the discharge by 2. The hydraulic gradient now becomes 26·4 ft. per mile, 1 in 200, or 5 per 1,000, and the discharge 1,300 cub. ft. The horizontal line of the reduced gradient cuts the vertical line of the reduced discharge on the 27-in. pipe curve, which is the diameter sought for.

Incidentally it may be mentioned that as the velocity depends solely upon the volume of discharge and size of pipe, it would be necessary to look where the 27-in. pipe curve cuts the vertical line of full discharge of 2,600 cub. ft. in order to ascertain the true velocity in the pipe. If, as in this particular instance, the diagram is not sufficiently large to enable this to be done, it is only necessary to divide the discharge in cubic feet per minute by 60 and by the area of the pipe in square feet:—

$$\frac{2,600}{60\times3{\cdot}98}=10{\cdot}9 \text{ ft. per second velocity.}$$

Ex. 5. What inclination or hydraulic gradient is required to give a discharge of 4,400 cub. ft. per min. through a 41-in. pipe? On referring to diagram No. 4, at the intersection of the vertical line, 4,400 and the curve of 41-in. diameter pipe, will be found the horizontal line giving the hydraulic gradient of 31 ft. per mile or 1 in 172 or 5·85 per 1,000 and the velocity is 8 ft. per second.

So far, the examples given relate solely to the diagrams which, it will be remembered, are drawn for a co-efficient of roughness $n=0{\cdot}013$.

Ex. 6. In example 1 we found that an 18-in. pipe on a certain gradient gave a discharge of 450 cub. ft. per minute. What discharge would this pipe give if the co-efficients of roughness were taken at 0·011 and 0·017, all other conditions being the same ?

Turning to Table I and on the line of 18-in. diameter pipe under the columns headed 0·011 and 0·017 respectively will be found the constants 1·2297 and 0·7148. Therefore, the 18-in. pipe as in example 1 with a co-efficient of roughness of 0·011 would give a discharge of :—

$$1{\cdot}2297 \times 450 = 553{\cdot}365 \text{ cub. ft. per minute.}$$

This same pipe with a co-efficient of roughness of 0·017 would only give a discharge of $0{\cdot}7148 \times 450 = 321{\cdot}66$ cub. ft. per minute.

To show the effect of roughness on the discharge, the discharges of the 18-in. pipe in example 1 for all the co-efficients are given below.

	n=·010	·011	·012	·013	·014	·015	·016	·017
Cub. ft. per min.,	= 622	553	497	450	410	376	347	322

Ex. 7. Again, in example 3 we found that the nearest size of pipe to discharge 3,000 cub. ft. per minute through a main 10,000 ft. long with an hydraulic gradient of 34 ft. per mile was 35 in. in diameter. What would be the size of pipe to discharge 3,000 cub. ft. per minute under similar conditions if the co-efficients of roughness were 0·012 and 0·015 ? In Table I on the line of 35 in. and under the columns ·012 and ·015 we find the constants 1·0972 and 0·8464. If we divide the discharge by these constants we get :—

$$\frac{3{,}000}{1{\cdot}0972} = 2{,}734 \text{ cub. ft. and } \frac{3{,}000}{0{\cdot}8464} = 3{,}545 \text{ cub. ft.}$$

On referring to diagram 3 at the points where the vertical lines 2,734 and 3,545 cut the horizontal line of the hydraulic gradient, we find the nearest sizes of pipes to be 34 and 37 respectively.

The following table shows the variation in the diameters of the pipes due to different co-efficients of roughness. The discharge and hydraulic gradient being similar to those in example 3 :—

	n=·010	·011	·012	·013	·014	·015	·016	·017
Diameter of pipe=	31	32½	34	35	36	37	38	39

In Table IV full particulars of d, D, R, $\sqrt{R}$, log. $\sqrt{R}$, A, log. A and P for each size of pipe ranging from 3 to 48 in. diameter will be found.

Table V gives the relative discharging capacities of pipes and also the relative ratio of discharging power calculated according to Flynn's modification of Kutter's

formula with a co-efficient of roughness of 0·013 and will facilitate the proper proportioning of pipe systems.

The gradients being equal, the discharges of pipes vary as the square root of the fifth power of the diameter ($\sqrt{D^5}$), but this statement is only approximately true as regards Kutter's formula owing to the variable quantities contained in the expression c of the formula.

For values of R (hydraulic mean depth in feet) of pipes varying from 3 to 48 in. in diameter and for gradients between 1 per 1,000 and 15 per 1,000 and with a co-efficient of roughness of 0·013, c varies from 55·5 to 116·5, and the expression $\sqrt{D^5}$ has to be multiplied by a factor m in order to take this variable quantity c into account and assumes the form of $\sqrt{D^5} \times m$ where $m = 0{\cdot}01\ c$.

This table gives the ratio of $\sqrt{D^5} \times m$ of any diameter of pipe from 3 to 48 in. to $\sqrt{D^5} \times m$ of any other diameter of pipe within the same limits. It will be seen that the relative ratio of discharging power of a 12-in. pipe to that of a 24-in. pipe is as 1 to 6·706; of a 15-in. pipe to a 36-in. one as 1 to 10·893, and of a 24-in. pipe to a 48-in. one as 1 to 6·516. The relative discharging power (see the column $\sqrt{D^5} \times m$) of a 24-in. pipe to that of a 48-in. pipe is as 5·720 to 37·28, and of a 6-in. pipe to that of a 36-in. pipe is as 0·1230 to 17·17.

Ex. 8. If an 18-in. pipe on a gradient of 1 in 185 gives a discharge of 450 cub. ft. per minute, it is required to know what discharge a 30-in. pipe will give on the same gradient.

Looking up the values of $\sqrt{D^5} \times m$ in Table V, we find :—

For 18-in. pipe $\sqrt{D^5} \times m = 2{\cdot}601$.

„ 30-in. „ $\sqrt{D^5} \times m = 10{\cdot}47$.

A simple proportion sum shows that :—

As 2·601 : 10·47 :: 450 to x.

or $\dfrac{450 \times 10{\cdot}47}{2{\cdot}601} = 1{,}811$ cub. ft. the capacity of a 30-in. pipe.

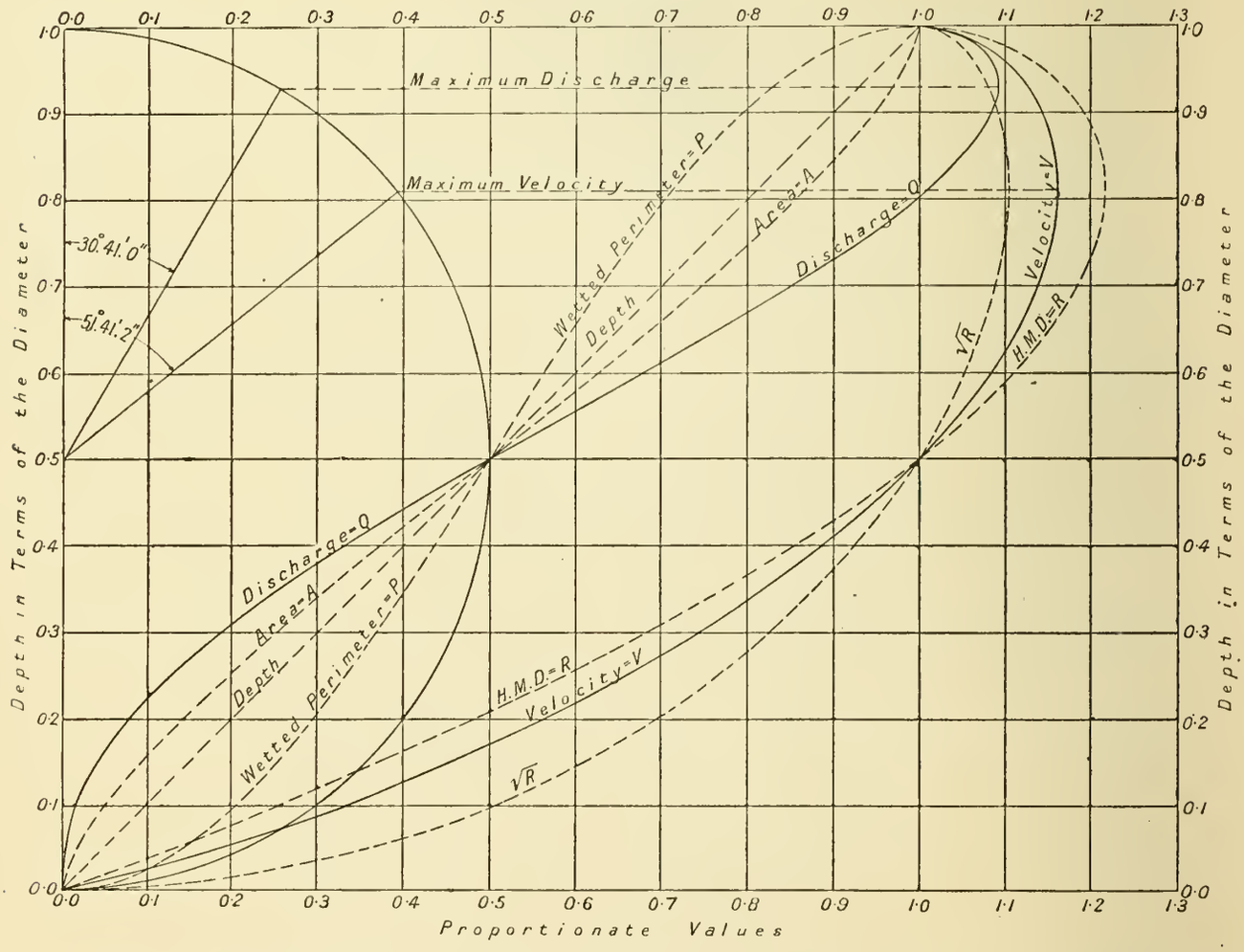
The same result can be had by looking up the relative ratio of discharging power of an 18-in. to a 30-in. pipe. In the column 18 and on the horizontal line of 30 is found the value 4·026. This figure multiplied by 450 gives 1,811 cub. ft.

Sewers

Although Diagrams Nos. 1 to 4 have been calculated and drawn for pipes running full and primarily for water supply, they are also applicable for ascertaining the discharge and velocity in sewers and other pipes when running partially full.

In Table VI is given the proportionate values of the discharge, velocity, area, wetted perimeter, hydraulic mean depth and square root of this dimension for every one-hundredth part of the depth of a pipe having a diameter of 1·0, and diagram No. 5 gives the result of this table in graphic form.

DIAGRAM 5.



From either this table or diagram it is easy to find the discharge in cubic feet per minute, velocity in feet per second, actual area of water, wetted perimeter, etc., of any diameter of pipe given in diagrams Nos. 1 to 4 at different depths of flow. The depth of flow is given in terms of the diameter, and the discharge, velocity, area, etc., when flowing full, is taken as unity.

The proportionate values of area, wetted perimeter, hydraulic mean depth and square root of same, are based upon the well-known properties of the circle but those relating to discharge and velocity are based upon the modification of Kutter's formula from which Diagrams Nos. 1 to 4 have been calculated.

DIAGRAM Nº 1

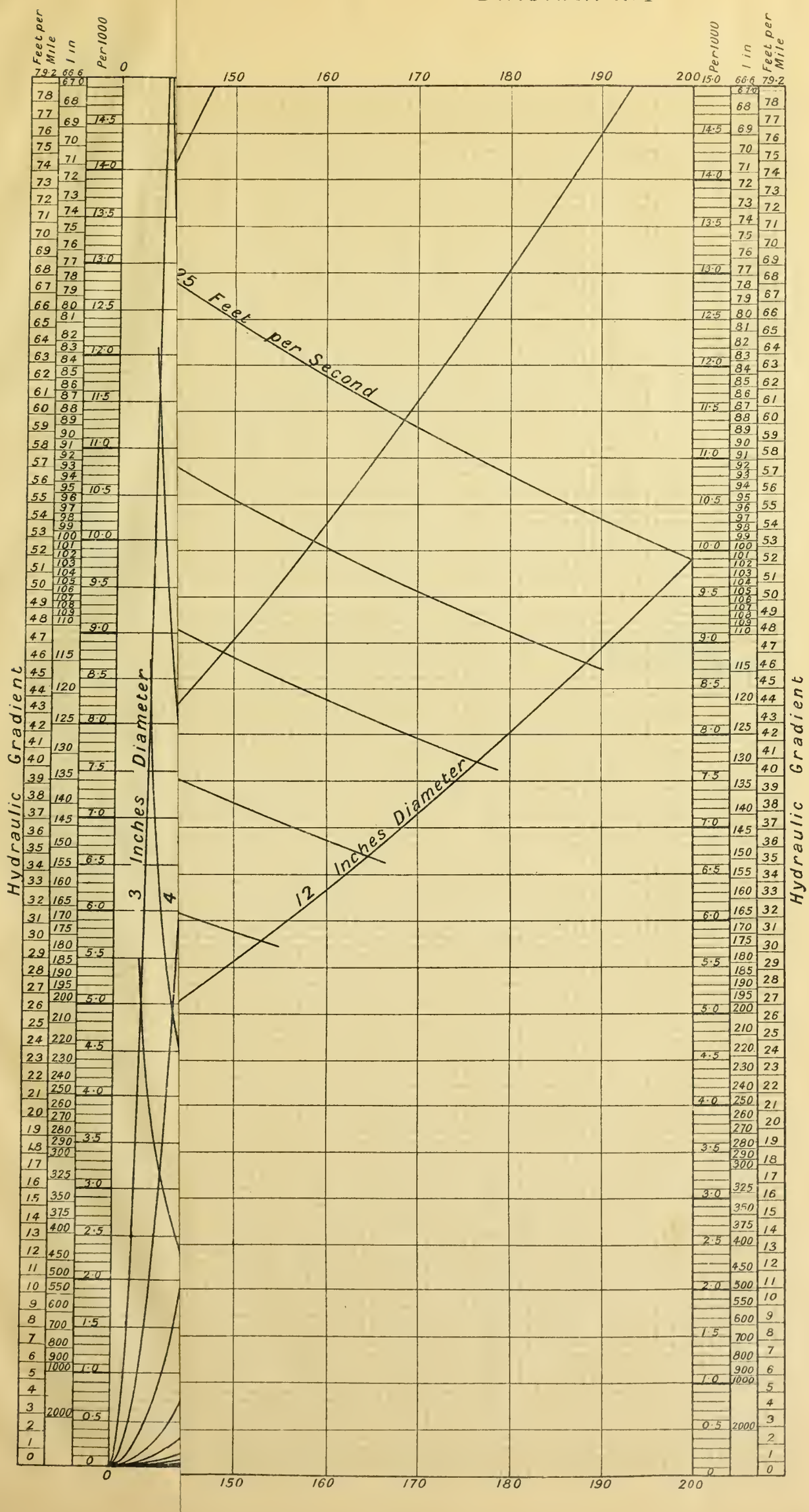

Feet per Mile
1 in
Per 1000
Hydraulic Gradient
0
150
160
170
180
190
200
25 Feet per Second
3 Inches Diameter
4
12 Inches Diameter

DIAGRAM Nº I

$n = 0.013$

Cubic Feet per Minute

Hydraulic Gradient — Feet per Mile — 1 in — Per 1000

3 Inches Diameter
4 "
5 "
6 "
7 "
8 "
9 "
10 "
11 "
12 "

4·25 Feet per Second
4·0 Feet per Second
3·75 " "
3·5 " "
3·25 " "
3·0 Feet per Second
2·75 " "
2·5 " "
2·25 " "
2·0 Feet per Second
1·75 " "
1·5 " "
1·25 " "
1·0 Foot per second

DIAGRAM No. II

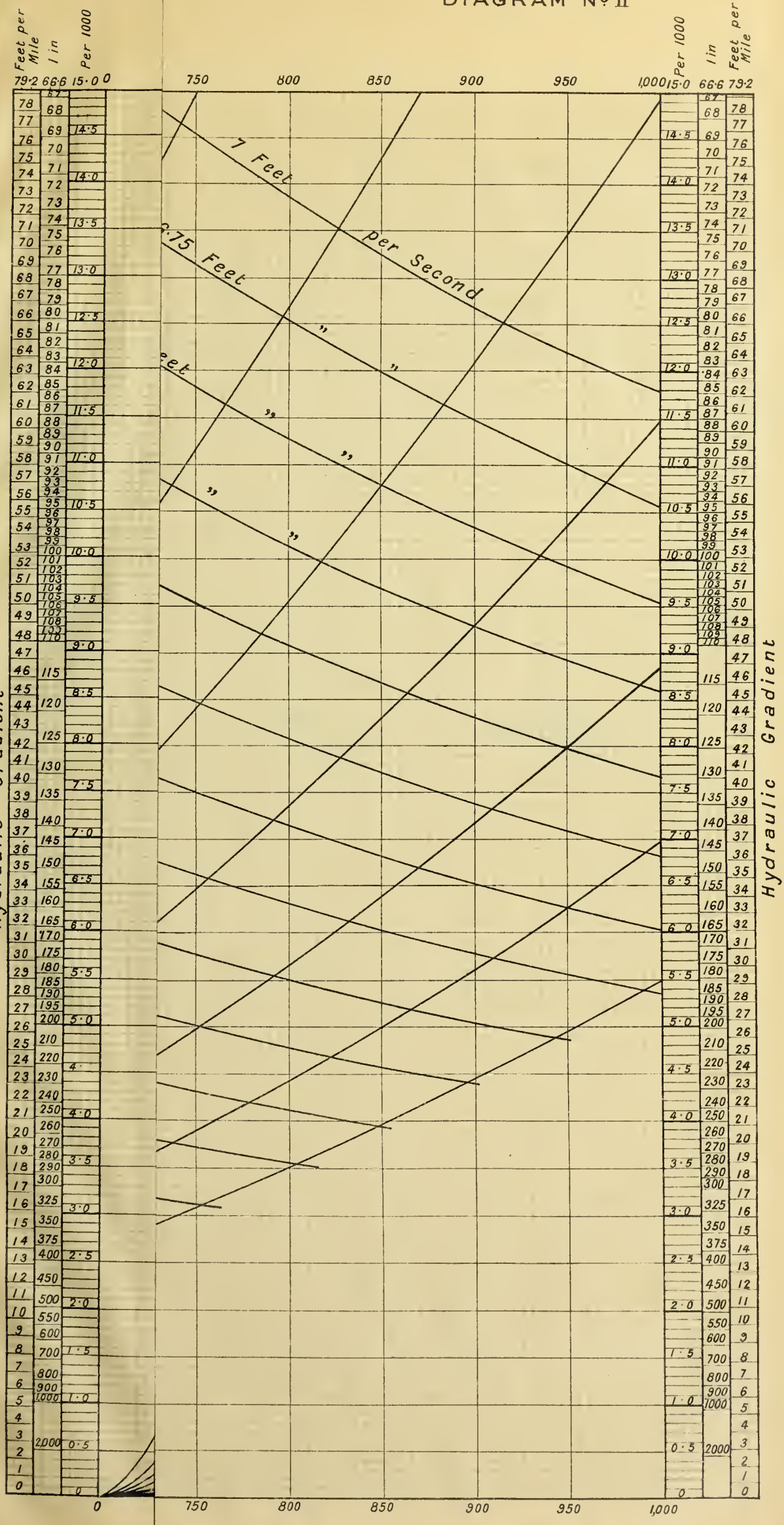


DIAGRAM Nº II

$n = 0.013$

Cubic Feet per minute.

Hydraulic Gradient

Feet per Mile | 1 in | Per 1000

10 Inches diameter
11 " "
12 " "
13 " "
14 " "
15 " "
16 " "
17 " "
18 " "
19 " "
20 " "
21 " "
22 " "
23 " "
24 " "

7 Feet per Second
6·75 Feet " "
6·5 Feet " "
6·25 Feet " "
6 Feet per Second
5·75 Feet " "
5·5 Feet " "
5·25 Feet " "
5 Feet per Second
4·75 Feet " "
4·5 Feet " "
4·25 Feet " "
4 Feet per Second
3·75 Feet " "
3·5 Feet " "
3·25 Feet " "
3 Feet per Second
2·75 Feet " "
2·5 Feet " "
2·25 Feet " "
2 Feet per Second

DIAGRAM Nº III

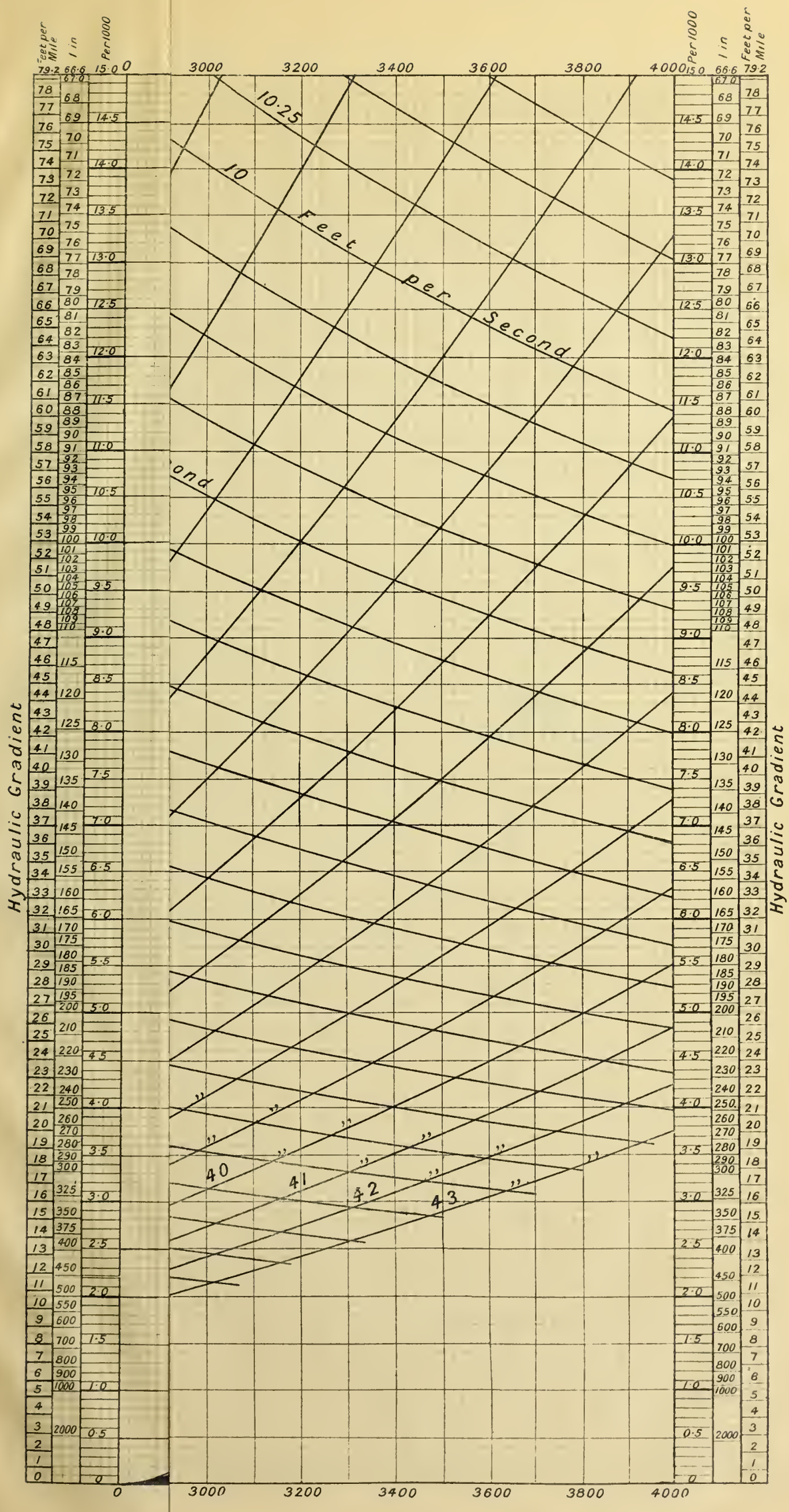
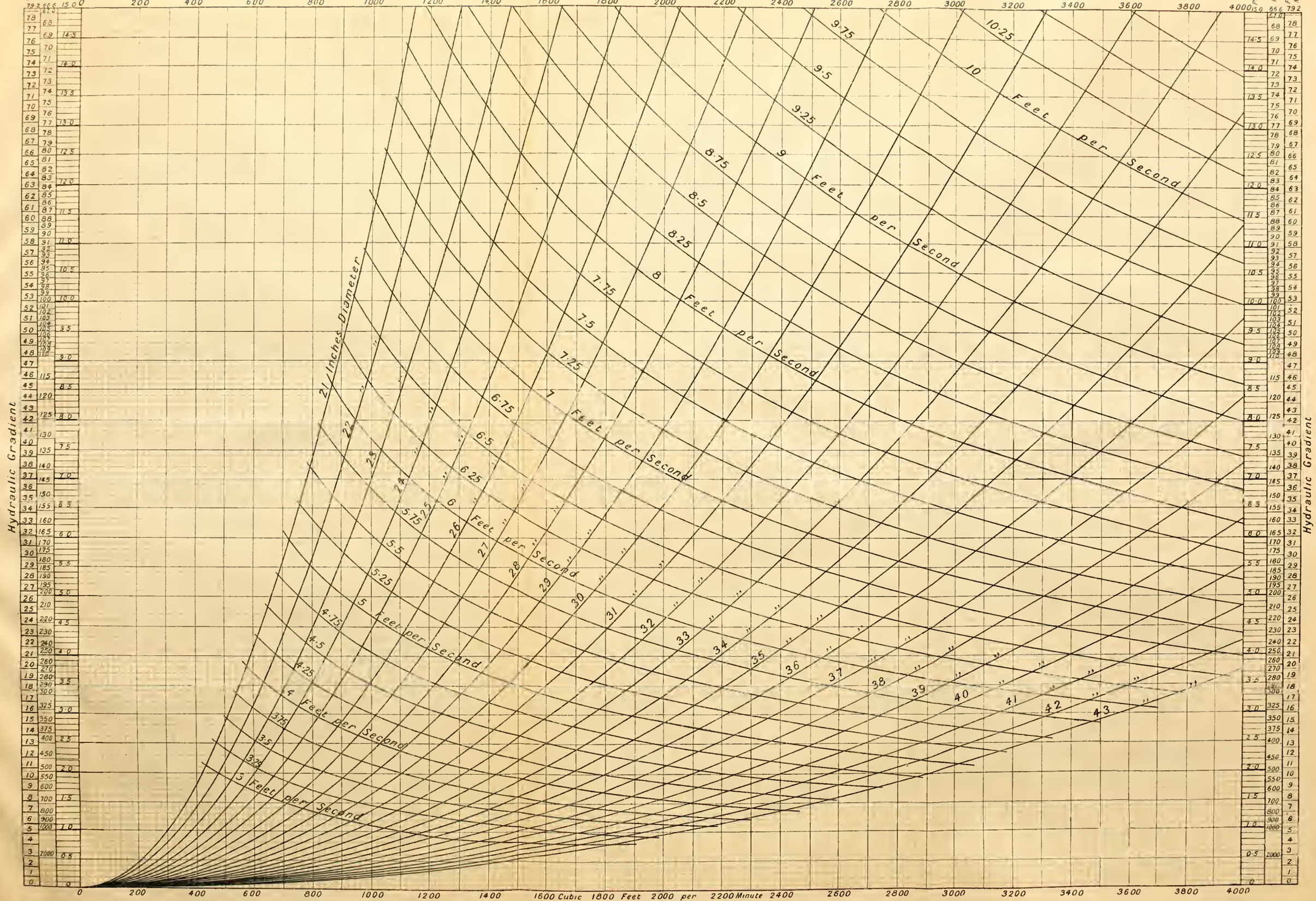


DIAGRAM Nº III

$n = 0.013$

Cubic Feet per Minute



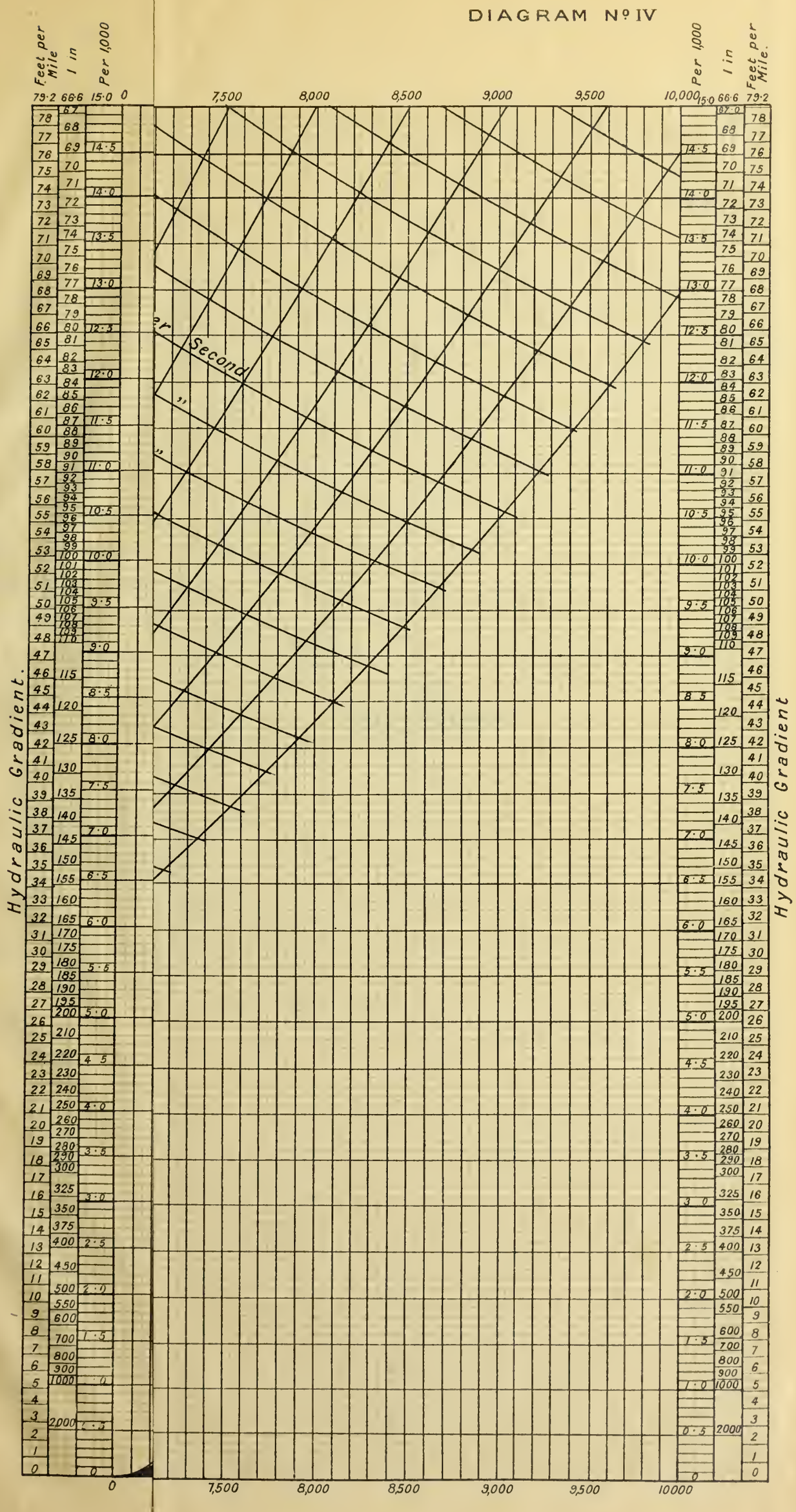


DIAGRAM Nº IV
Feet per Mile
1 in
Per 1,000
Hydraulic Gradient.
Hydraulic Gradient
Per 1,000
1 in
Feet per Mile.
7,500
8,000
8,500
9,000
9,500
10,000
Second
"
"

DIAGRAM Nº IV

$n = 0{\cdot}013$

Cubic feet per minute

Hydraulic Gradient.

Feet per Mile | 1 in | Per 1,000

0 | 500 | 1,000 | 1,500 | 2,000 | 2,500 | 3,000 | 3,500 | 4,000 | 4,500 | 5,000 | 5,500 | 6,000 | 6,500 | 7,000 | 7,500 | 8,000 | 8,500 | 9,000 | 9,500 | 10,000

12 Feet per Second
11·75 " " "
11·5 " " "
11·25 " " "
11 Feet per Second
10·75 " " "
10·5 " " "
10·25 " " "
10 Feet per Sec.
9·75 " " "
9·5 " " "
9·25 " " "
9 Ft. per Sec.
8·75 " " "
8·5 " " "
8·25 " " "
8 Ft. per Sec.
7·75 " " "
7·5 " " "
7·25 " " "
7 Ft. per Sec.
6·75 " " "
6·5 " " "
6·25 " " "
6 Ft. per Sec.
5·75 " " "
5·5 " " "
5·25 " " "
5 Ft. per Sec.
4·75 " " "
4·5 " " "
4·25 " " "
4 Ft. per Sec.

26 Inches Diameter
27 " "
28 " "
29 " "
30 " "
31 " "
32 " "
33 " "
34 " "
35 " "
36 " "
37 " "
38 " "
39 " "
40 " "
41 " "
42 " "
43 " "
44 " "
45 " "
46 " "
47 " "
48 " "

Cubic feet per minute.

Hydraulic Gradient

Ex. 9. Let it be required to find the discharge and velocity of an 18-inch diameter pipe with an inclination of 1 in 185 when running quarter full ; the co-efficient of roughness n being taken at 0·013. The method of ascertaining the discharge and velocity of this diameter of pipe when full from diagram No. 2 is given in example 1, from which it will be seen that this pipe will discharge 450 cubic feet per minute with a velocity of 4·25 feet per second.

To find the discharge and velocity of a pipe when running partially full, it is only necessary to multiply the figures of the discharge and velocity of the pipe when full by the proportionate values of discharge and velocity at the particular depth of flow as given in Table VI or read direct from Diagram 5.

In this example the pipe is running quarter full. On referring to Table VI and on the line of 0·25 depth of flow will be found the proportionate values, under their respective columns, of discharge and velocity, viz., ·1286 and ·6580.

450 × ·1286 = 57·87 cubic feet of water per minute.

4·25 × ·6580 = 2·796 velocity in feet per second.

In order to ascertain the area, wetted perimeter, etc., of water way of the pipe in question at any particular depth of flow, the following example will show how this can be done from the proportionate values given in the table.

In Table IV the following particulars of an 18-in. diameter pipe, when full, will be found, viz. :—

Diameter of pipe	= 1·5 ft.
Area of pipe	= 1·7671 square ft.
Wetted perimeter	= 4·7124 ft.
Hydraulic mean depth	= ·375 ft.
$\sqrt{R}$	= ·6124 ft.

It is only necessary to multiply these figures by the proportionate values given in Table VI to get the desired results. Thus, for an 18-in. diameter pipe when running 0·25 full :—

Depth of flow	1·5	× ·25	= ·375 ft. = 4½ in.
Area of water way	1·7671	× ·1955	= ·34546 square ft.
Wetted perimeter	4·7124	× ·3333	= 1·5706 ft.
Hydraulic mean depth . . .	·375	× ·5865	= ·21993 ft.
$\sqrt{R}$	·6124	× ·7658	= ·46897 ft.

On referring to Diagram 5 or Table VI, it will be seen that by Kutter's formula the maximum discharge of a circular pipe takes place when the depth of flow is ·93, the diameter and the velocity reaches its maximum when the depth of flow is ·81 the diameter. In other words if the discharge and velocity of a pipe, when running full, are taken as unity, the maximum discharge is 1·0915 and the maximum velocity 1·1616 that of a pipe when full.

TABLE I.

Table of Constants.

To be used as multipliers in problems involving discharge.

To be used as divisors in problems involving diameter of pipes.

Diameter of Pipe in Inches.	·010	·011	·012	·013	·014	·015	·016	·017
3	1·4631	1·2748	1·1236	1·0000	·8976	·8118	·7388	·6763
4	1·4507	1·2679	1·1207	1·0000	·8997	·8153	·7434	·6817
5	1·4408	1·2625	1·1184	1·0000	·9014	·8182	·7472	·6861
6	1·4325	1·2579	1·1165	1·0000	·9028	·8206	·7504	·6899
7	1·4255	1·2539	1·1148	1·0000	·9040	·8227	·7532	·6932
8	1·4194	1·2506	1·1134	1·0000	·9051	·8246	·7557	·6961
9	1·4140	1·2476	1·1121	1·0000	·9060	·8263	·7579	·6987
10	1·4094	1·2448	1·1108	1·0000	·9068	·8276	·7599	·7013
11	1·4049	1·2422	1·1098	1·0000	·9076	·8290	·7617	·7036
12	1·4007	1·2396	1·1089	1·0000	·9084	·8301	·7634	·7059
13	1·3970	1·2378	1·1080	1·0000	·9091	·8314	·7649	·7077
14	1·3933	1·2360	1·1072	1·0000	·9097	·8326	·7664	·7094
15	1·3896	1·2344	1·1064	1·0000	·9103	·8337	·7678	·7112
16	1·3866	1·2326	1·1056	1·0000	·9108	·8347	·7691	·7125
17	1·3838	1·2312	1·1050	1·0000	·9113	·8356	·7703	·7139
18	1·3814	1·2297	1·1044	1·0000	·9118	·8365	·7714	·7148
19	1·3794	1·2285	1·1039	1·0000	·9123	·8374	·7725	·7160
20	1·3774	1·2272	1·1034	1·0000	·9127	·8382	·7736	·7173
21	1·3754	1·2258	1·1027	1·0000	·9131	·8388	·7745	·7185
22	1·3734	1·2246	1·1023	1·0000	·9135	·8395	·7754	·7196
23	1·3715	1·2235	1·1018	1·0000	·9139	·8402	·7763	·7207
24	1·3696	1·2224	1·1013	1·0000	·9142	·8408	·7772	·7217
25	1·3679	1·2214	1·1008	1·0000	·9145	·8414	·7780	·7227
26	1·3661	1·2204	1·1004	1·0000	·9148	·8420	·7788	·7237
27	1·3645	1·2195	1·1000	1·0000	·9152	·8426	·7795	·7246
28	1·3629	1·2186	1·0996	1·0000	·9155	·8431	·7803	·7254
29	1·3614	1·2177	1·0992	1·0000	·9158	·8436	·7810	·7263
30	1·3599	1·2169	1·0988	1·0000	·9161	·8441	·7817	·7271
31	1·3585	1·2161	1·0985	1·0000	·9164	·8446	·7824	·7278
32	1·3572	1·2153	1·0982	1·0000	·9167	·8451	·7830	·7286
33	1·3559	1·2146	1·0979	1·0000	·9169	·8455	·7836	·7294
34	1·3547	1·2139	1·0975	1·0000	·9171	·8460	·7842	·7301
35	1·3535	1·2132	1·0972	1·0000	·9174	·8464	·7847	·7308
36	1·3523	1·2125	1·0969	1·0000	·9176	·8468	·7853	·7315
37	1·3512	1·2119	1·0966	1·0000	·9179	·8472	·7859	·7322
38	1·3501	1·2113	1·0964	1·0000	·9181	·8476	·7864	·7328
39	1·3490	1·2106	1·0961	1·0000	·9183	·8480	·7869	·7335
40	1·3480	1·2100	1·0958	1·0000	·9185	·8484	·7874	·7341
41	1·3470	1·2095	1·0956	1·0000	·9187	·8487	·7879	·7346
42	1·3461	1·2089	1·0954	1·0000	·9189	·8491	·7884	·7352
43	1·3452	1·2084	1·0951	1·0000	·9190	·8495	·7889	·7358
44	1·3443	1·2078	1·0948	1·0000	·9192	·8498	·7894	·7363
45	1·3433	1·2073	1·0946	1·0000	·9194	·8501	·7897	·7368
46	1·3425	1·2068	1·0944	1·0000	·9195	·8504	·7901	·7374
47	1·3416	1·2063	1·0942	1·0000	·9197	·8507	·7905	·7379
48	1·3408	1·2058	1·0940	1·0000	·9199	·8510	·7910	·7384

TABLE II.

1 cubic foot=6·22786 gallons.

Cubic Feet per Minute.	Gallons per Minute.	Cubic Feet per hour.	Gallons per Hour.	Cubic Feet per Day.	Gallons per Day.
1	6·23	60	373·7	1,440	8,968·1
2	12·45	120	747·3	2,880	17,936·2
3	18·68	180	1,121·0	4,320	26,904·3
4	24·91	240	1,494·7	5,760	35·872·5
5	31·14	300	1,868·3	7,200	44,840·6
6	37·37	360	2,242·0	8,640	53,808·7
7	43·59	420	2,615·7	10,080	62,776·8
8	49·82	480	2,989·4	11,520	71,744·9
9	56·05	540	3,363·0	12,960	80,713·1
10	62·28	600	3,736·7	14,400	89,681·2
20	124·5	1,200	7,473	28,800	179,362
30	186·8	1,800	11,210	43,200	269,043
40	249·1	2,400	14,947	57,600	358,725
50	311·4	3,000	18,683	72,000	448,406
60	373·7	3,600	22,420	86,400	538,087
70	435·9	4,200	26,157	100,800	627,768
80	498·2	4,800	29,894	115,200	717,449
90	560·5	5,400	33,630	129,600	807,131
100	622·8	6,000	37,367	144,000	896,812
110	685·1	6,600	41,104	158,400	986,493
120	747·3	7,200	44,841	172,800	1,076,174
130	809·6	7,800	48,577	187,200	1,165,855
140	871·9	8,400	52,314	201,600	1,255,536
150	934·2	9,000	56,051	216,000	1,345,218
160	996·4	9,600	59,787	230,400	1,434,899
170	1,058·7	10,200	63,524	244,800	1,524,580
180	1,121·0	10,800	67,261	259,200	1,614,261
190	1,183·3	11,400	70,998	273,600	1,703,942
200	1,245	12,000	74,734	288,000	1,793,624
250	1,557	15,000	93,418	360,000	2,242,030
300	1,868	18,000	112,101	432,000	2,690,435
350	2,180	21,000	130,785	504,000	3,138,841
400	2,491	24,000	149,468	576,000	3,587,247
450	2,802	27,000	168,152	648,000	4,035,653
500	3,114	30,000	186,836	720,000	4,484,059
550	3,425	33,000	205,519	792,000	4,932,465
600	3,737	36,000	224,203	864,000	5,380,871
650	4,048	39,000	242,886	936,000	5,829,277
700	4,359	42,000	261,570	1,008,000	6,277,683
750	4,671	45,000	280,254	1,080,000	6,726,089
800	4,982	48,000	298,937	1,152,000	7,174,495
850	5,294	51,000	317,621	1,224,000	7,622,901
900	5,605	54,000	336,304	1,296,000	8,071,306
950	5,916	57,000	354,988	1,368,000	8,519,712
1,000	6,228	60,000	373,672	1,440,000	8,968,118
1,500	9,342	90,000	560,507	2,160,000	13,452,178
2,000	12,456	120,000	747,343	2,880,000	17,936,237
2,500	15,570	150,000	934,179	3,600,000	22,420,296
3,000	18,683	180,000	1,121,015	4,320,000	26,904,355
3,500	21,797	210,000	1,307,851	5,040,000	31,388,414
4,000	24,911	240,000	1,494,686	5,760,000	35,872,474
4,500	28,025	270,000	1,681,522	6,480,000	40,356,533
5,000	31,139	300,000	1,868,358	7,200,000	44,840,592
6,000	37,367	360,000	2,242,030	8,640,000	53,808,710
7,000	43,595	420,000	2,615,701	10,080,000	62,776,829
8,000	49,823	480,000	2,989,373	11,520,000	71,744,947
9,000	56,051	540,000	3,363,044	12,960,000	80,713,066
10,000	62,279	600,000	3,736,716	14,400,000	89,681,184
11,000	68,506	660,000	4,110,388	15,840,000	98,649,302
12,000	74,734	720,000	4,484,059	17,280,000	107,617,421
13,000	80,962	780,000	4,857,731	18,720,000	116,585,540
14,000	87,190	840,000	5,231,402	20,160,000	125,553,658
15,000	93,418	900,000	5,605,074	21,600,000	134,521,776
16,000	99,646	960,000	5,978,746	23,040,000	143,489,894

TABLE III.

1 gallon=0·160569 cubic foot.

Gallons per Minute.	Cubic Feet per Minute.	Gallons per Hour.	Cubic Feet per Hour.	Gallons per Day.	Cubic Feet per Day.
1	0·160	60	9·63	1,440	231·2
2	0·321	120	19·27	2,880	462·4
3	0·482	180	28·90	4,320	693·6
4	0·642	240	38·54	5,760	924·9
5	0·803	300	48·17	7,200	1,156·1
6	0·963	360	57·80	8,640	1,387·3
7	1·124	420	67·44	10,080	1,618·5
8	1·284	480	77·07	11,520	1,849·7
9	1·445	540	86·71	12,960	2,080·9
10	1·606	600	96·34	14,400	2,312·2
20	3·211	1,200	192·68	28,800	4,624·4
30	4·817	1,800	289·02	43,200	6,936·6
40	6·423	2,400	385·36	57,600	9,248·8
50	8·028	3,000	481·71	72,000	11,561·0
60	9·634	3,600	578·05	86,400	13,873·2
70	11·240	4,200	674·39	100,800	16,185·3
80	12·845	4,800	770·73	115,200	18,497·5
90	14·451	5,400	867·07	129,600	20,809·7
100	16·057	6,000	963·41	144,000	23,121·9
200	32·114	12,000	1,926·8	288,000	46,244
300	48·171	18,000	2,890·2	432,000	69,366
400	64·228	24,000	3,853·6	576,000	92,488
500	80·284	30,000	4,817·1	720,000	115,610
600	96·341	36,000	5,780·5	864,000	138,732
700	112·398	42,000	6,743·9	1,008,000	161,853
800	128·455	48,000	7,707·3	1,152,000	184,975
900	144·512	54,000	8,670·7	1,296,000	208,097
1,000	160·569	60,000	9,634·1	1,440,000	231,219
1,100	176·63	66,000	10,597	1,584,000	254,341
1,200	192·68	72,000	11,561	1,728,000	277,463
1,300	208·74	78,000	12,524	1,872,000	300,585
1,400	224·80	84,000	13,488	2,016,000	323,707
1,500	240·85	90,000	14,451	2,160,000	346,829
1,600	256·91	96,000	15,415	2,304,000	369,951
1,700	272·97	102,000	16,378	2,448,000	393,073
1,800	289·02	108,000	17,341	2,592,000	416,195
1,900	305·08	114,000	18,305	2,736,000	439,317
2,000	321·14	120,000	19,268	2,880,000	462,439
2,100	337·19	126,000	20,232	3,024,000	485,561
2,200	353·25	132,000	21,195	3,168,000	508,683
2,300	369·31	138,000	22,158	3,312,000	531,804
2,400	385·36	144,000	23,122	3,456,000	554,926
2,500	401·42	150,000	24,085	3,600,000	578,048
2,600	417·48	156,000	25,049	3,744,000	601,170
2,700	433·54	162,000	26,012	3,888,000	624,292
2,800	449·59	168,000	26,975	4,032,000	647,414
2,900	465·65	174,000	27,939	4,176,000	670,536
3,000	481·7	180,000	28,902	4,320,000	693,658
4,000	642·3	240,000	38,536	5,760,000	924,877
5,000	802·8	300,000	48,171	7,200,000	1,156,097
6,000	963·4	360,000	57,805	8,640,000	1,387,316
7,000	1,124·0	420,000	67,439	10,080,000	1,618,535
8,000	1,284·5	480,000	77,073	11,520,000	1,849,755
9,000	1,445·1	540,000	86,707	12,960,000	2,080,974
10,000	1,605·7	600,000	96,341	14,400,000	2,312,194
20,000	3,211·4	1,200,000	192,683	28,800,000	4,624,387
30,000	4,817·1	1,800,000	289,024	43,200,000	6,936,581
40,000	6,422·8	2,400,000	385,366	57,600,000	9,248,774
50,000	8,028·4	3,000,000	481,707	72,000,000	11,560,968
60,000	9,634·1	3,600,000	578,048	86,400,000	13,873,162
70,000	11,239·8	4,200,000	674,390	100,800,000	16,185,355
80,000	12,845·5	4,800,000	770,731	115,200,000	18,497,549
90,000	14,451·2	5,400,000	867,073	129,600,000	20,809,742
100,000	16,056·9	6,000,000	963,414	144,000,000	23,121,936

TABLE IV.

Diameter in Inches. $d.$	Diameter in Feet $D.$	Hydraulic Mean Depth in Feet. $R.$	$\sqrt{R}.$	Log $\sqrt{R}.$	Area of Pipe in Square Feet. $A.$	Log $A.$	Wetted Perimeter when full in Feet. $P.$
3	0·25	·0625	·25	$\bar{1}$·3979400	0·04908	$\bar{2}$·6909046	0·7854
4	0·3333	·0833	·2886	$\bar{1}$·4602963	0·08727	$\bar{2}$·9408650	1·0472
5	0·4167	·1042	·3228	$\bar{1}$·5089335	0·13655	$\bar{1}$·1352917	1·3090
6	0·5	·125	·3535	$\bar{1}$·5483894	0·19635	$\bar{1}$·2930309	1·5708
7	0·5833	·1458	·3818	$\bar{1}$·5818359	0·26725	$\bar{1}$·4269177	1·8326
8	0·6667	·1667	·4082	$\bar{1}$·6108730	0·34906	$\bar{1}$·5429001	2·0944
9	0·75	·1875	·4330	$\bar{1}$·6364879	0·44179	$\bar{1}$·6452159	2·3562
10	0·8333	·2083	·4564	$\bar{1}$·6593456	0·54543	$\bar{1}$·7367390	2·6180
11	0·9167	·2292	·4787	$\bar{1}$·6800634	0·65995	$\bar{1}$·8195110	2·8798
12	1·0	·25	·5	$\bar{1}$·6989700	0·7854	$\bar{1}$·8950909	3·1416
13	1·0833	·2708	·5204	$\bar{1}$·7163373	0·9217	$\bar{1}$·9645896	3·4034
14	1·1667	·2917	·5400	$\bar{1}$·7323938	1·0690	·0289777	3·6652
15	1·25	·3125	5590	$\bar{1}$·7474118	1·2272	·0889153	3·9270
16	1·3333	·3333	·5773	$\bar{1}$·7614016	1·3963	·1449787	4·1888
17	1·4167	·3542	·5951	$\bar{1}$·7745900	1·5763	·1976389	4·4506
18	1·5	·375	·6124	$\bar{1}$·7870352	1·7671	·2472611	4·7124
19	1·5833	·3958	·6291	$\bar{1}$·7987197	1·9690	2942457	4·9742
20	1·6667	·4167	·6455	$\bar{1}$·8098962	2·1817	3387950	5·2360
21	1·75	·4375	·6614	$\bar{1}$·8204642	2·4053	·3811693	5·4978
22	1·8333	·4583	·6770	$\bar{1}$·8305887	2·6398	·4215710	5·7596
23	1·9167	·4792	·6922	$\bar{1}$·8402316	2·8853	·4601910	6·0214
24	2·0	·5	·7071	$\bar{1}$·8494808	3·1416	·4971509	6·2832
25	2·0833	·5208	·7217	$\bar{1}$·8583567	3·4088	·5326015	6·5450
26	2·1667	·5417	·7360	$\bar{1}$·8668778	3·6870	·5666731	6·8068
27	2·25	·5625	·75	$\bar{1}$·8750613	3·9761	·5994573	7·0686
28	2·3333	·5833	·7637	$\bar{1}$·8829228	4·2761	·6310479	7·3304
29	2·4167	·6042	·7773	$\bar{1}$·8905887	4·5869	·6615193	7·5922
30	2·5	·625	·7906	$\bar{1}$·8979568	4·9087	·6909665	7·8540
31	2·5833	·6458	·8036	$\bar{1}$·9050399	5·2415	·7194556	8·1158
32	2·6667	·6667	·8165	$\bar{1}$·9119562	5·5852	·7470387	8·3776
33	2·75	·6875	·8291	$\bar{1}$·9186069	5·9396	·7737572	8·6394
34	2·8333	·7083	·8416	$\bar{1}$·9251057	6·3050	·7996851	8·9012
35	2·9167	·7292	·8539	$\bar{1}$·9314070	6·6813	·8248610	9·1630
36	3·0	·75	·8660	$\bar{1}$·9375179	7·0686	·8493334	9·4248
37	3·0833	·7708	·8779	$\bar{1}$·9434450	7·4668	8731345	9·6866
38	3·1667	·7917	·8897	$\bar{1}$·9492436	7·8758	8962947	9·9484
39	3·25	·8125	·9014	$\bar{1}$·9549176	8·2958	9188583	10·2102
40	3·3333	·8333	·9128	$\bar{1}$·9603756	8·7267	·9408500	10·4720
41	3·4167	·8542	·9242	$\bar{1}$·9657660	9·1685	·9622983	10·7338
42	3·5	·875	·9354	$\bar{1}$·9709974	9·6211	·9832247	10·9956
43	3·5833	·8958	·9465	$\bar{1}$·9761206	10·085	1·0036759	11·2574
44	3·6667	·9167	·9574	$\bar{1}$·9810934	10·559	1·0236228	11·5192
45	3·75	·9375	·9682	$\bar{1}$·9859651	11·045	1·0431657	11·7810
46	3·8333	·9583	·9789	$\bar{1}$·9907383	11·541	1·0622434	12·0428
47	3·9167	·9792	·9895	$\bar{1}$·9954158	12·048	1·0809150	12·3046
48	4·0	1·0	1·0	0·0000000	12·566	1·0991971	12·5664

TABLE V.

RELATIVE DISCHARGING CAPACITIES

Dia. in In. d	Dia. in Ft. D	$\sqrt{D^5} \times m$	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
48	4·0	37·28									55·705	43·698	35·136	28·628	23·652	19·815	16·752	14·332	12·351	10·726	9·405
47	3·9167	35·25									52·669	41·317	32·220	27·068	22·365	18·736	15·840	13·553	11·677	10·141	8·892
46	3·8333	33·24									49·660	38·964	31·326	25·526	21·089	17·669	14·938	12·780	11·011	9·563	8·386
45	3·75	31·30								61·110	46·770	36·691	29·502	24·036	19·857	16·637	14·066	12·033	10·370	9·004	7·896
44	3·6667	29·47								57·530	44·032	34·542	27·774	22·630	18·700	15·664	13·242	11·330	9·762	8·478	7·434
43	3·5833	27·71								54·098	41·400	32·482	26·115	21·280	17·580	14·730	12·453	10·654	9·180	7·972	6·990
42	3·5	25·98								50·714	38·820	30·454	24·488	19·950	16·482	13·810	11·674	9·988	8·606	7·474	6·554
41	3·4167	24·38							63·770	47·591	36·428	28·576	22·975	18·721	15·469	12·960	10·954	9·372	8·076	7·013	6·150
40	3·3333	22·85							59·765	44·612	34·143	26·788	21·540	17·549	14·497	12·147	10·271	8·786	7·570	6·574	5·756
39	3·25	21·31							55·740	41·600	31·840	24·978	20·082	16·363	13·520	11·327	9·576	8·192	7·059	6·130	5·375
38	3·1667	19·88							52·000	38·824	29·707	23·306	18·739	15·267	12·613	10·568	8·934	7·644	6·586	5·719	5·015
37	3·0833	18·49							48·365	36·096	27·627	21·672	17·426	14·200	11·732	9·827	8·308	7·108	6·125	5·319	4·664
36	3·0	17·17						62·360	44·910	33·525	25·658	20·127	16·184	13·184	10·893	9·126	7·716	6·601	5·688	4·940	4·331
35	2·9167	15·91						57·794	41·614	31·061	23·772	18·651	14·995	12·218	10·094	8·457	7·149	6·117	5·271	4·577	4·014
34	2·8333	14·72						53·465	38·500	28·736	21·993	17·253	13·872	11·304	9·338	7·823	6·614	5·658	4·876	4·234	3·713
33	2·75	13·57						49·284	35·490	26·490	20·274	15·905	12·787	10·419	8·608	7·212	6·098	5·216	4·495	3·903	3·423
32	2·6667	12·49						45·362	32·670	24·385	18·662	14·641	11·772	9·591	7·924	6·639	5·612	4·802	4·137	3·593	3·151
31	2·5833	11·48					60·515	41·700	30·029	22·416	17·155	13·459	10·821	8·817	7·284	6·103	5·159	4·414	3·803	3·303	2·896
30	2·5	10·47					55·195	38·032	27·386	20·446	15·646	12·274	9·868	8·042	6·643	5·566	4·705	4·026	3·469	3·012	2·642
29	2·4167	9·559					50·388	34·720	25·000	18·663	14·283	11·206	9·009	7·341	6·065	5·081	4·296	3·675	3·167	2·750	2·412
28	2·3333	8·697					45·845	31·590	22·750	16·981	12·996	10·195	8·197	6·679	5·518	4·623	3·908	3·344	2·881	2·502	2·194
27	2·25	7·873				64·010	41·500	28·596	20·595	15·372	11·766	9·230	7·421	6·046	4·995	4·185	3·538	3·027	2·608	2·265	1·986
26	2·1667	7·106				57·775	40·660	25·814	18·588	13·874	10·618	8·330	6·698	5·456	4·508	3·777	3·193	2·732	2·354	2·044	1·793
25	2·0833	6·393				51·970	33·695	23·221	16·720	12·481	9·552	7·492	6·024	4·909	4·056	3·398	2·873	2·458	2·118	1·839	1·613
24	2·0	5·720				46·507	30·152	20·780	14·963	11·170	8·548	6·706	5·392	4·393	3·629	3·041	2·571	2·199	1·895	1·646	1·443
23	1·9167	5·091				41·386	26·836	18·492	13·316	10·408	7·607	5·966	4·798	3·909	3·230	2·706	2·288	1·957	1·687	1·465	1·284
22	1·8333	4·509			61·260	36·661	23·768	16·380	11·796	8·804	6·738	5·285	4·250	3·462	2·861	2·397	2·026	1·734	1·494	1·297	1·138
21	1·75	3·964			53·852	32·228	20·895	14·400	10·370	7·740	5·923	4·646	3·736	3·044	2·515	2·107	1·782	1·524	1·313	1·140	1
20	1·6667	3·476			47·220	28·260	18·322	12·626	9·091	6·786	5·193	4·074	3·276	2·669	2·205	1·848	1·562	1·336	1·151	1	
19	1·5833	3·018			41·000	24·538	15·909	10·962	7·894	5·892	4·509	3·538	2·844	2·318	1·915	1·604	1·356	1·160	1		
18	1·5	2·601		66·180	35·336	21·147	13·710	9·447	6·803	5·078	3·886	3·049	2·451	1·997	1·650	1·382	1·169	1			
17	1·4167	2·225		56·610	30·225	18·089	11·729	8·082	5·820	4·343	3·324	2·608	2·097	1·709	1·412	1·183	1				
16	1·3333	1·881		47·856	25·552	15·292	9·914	6·832	4·920	3·672	2·810	2·205	1·773	1·444	1·193	1					
15	1·25	1·576		40·101	21·412	12·813	8·307	5·724	4·122	3·077	2·355	1·847	1·485	1·210	1						
14	1·1667	1·302		33·125	17·688	10·584	6·862	4·729	3·405	2·542	1·945	1·526	1·227	1							
13	1·0833	1·061	61·325	26·996	14·413	8·625	5·592	3·854	2·775	2·071	1·585	1·244	1								
12	1·0	0·8530	49·302	21·705	11·588	6·936	4·496	3·098	2·231	1·665	1·274	1									
11	0·9167	0·6692	38·680	17·029	9·090	5·440	3·527	2·431	1·750	1·306	1										
10	0·8333	0·5121	29·600	13·031	6·957	4·163	2·699	1·860	1·340	1											
9	0·75	0·3823	22·096	9·726	5·193	3·108	2·015	1·388	1												
8	0·6667	0·2753	15·913	7·005	3·740	2·238	1·451	1													
7	0·5833	0·1897	10·960	4·827	2·577	1·542	1														
6	0·5	0·1230	7·108	3·129	1·671	1															
5	0·4167	0·0736	4·254	1·873	1																
4	0·3333	0·0393	2·271	1																	
3	0·25	0·0173	1																		

TABLE V.

OF FULL PIPES.

22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
8·267	7·322	6·516	5·830	5·244	4·734	4·287	3·899	3·560	3·247	2·984	2·747	2·532	2·343	2·171	2·016	1·875	1·749	1·631	1·529	1·435	1·345	1·265	1·191	1·121	1·057	1
7·816	6·922	6·161	5·512	4·958	4·476	4·054	3·687	3·366	3·070	2·822	2·597	2·394	2·215	2·053	1·906	1·773	1·654	1·542	1·445	1·357	1·272	1·196	1·126	1·060	1	
7·372	6·527	5·810	5·198	4·676	4·221	3·823	3·477	3·174	2·895	2·661	2·449	2·258	2·089	1·936	1·798	1·672	1·560	1·454	1·363	1·279	1·200	1·128	1·062	1		
6·942	6·147	5·471	4·895	4·404	3·975	3·599	3·274	2·990	2·726	2·506	2·306	2·126	1·967	1·823	1·693	1·574	1·469	1·370	1·284	1·205	1·130	1·062	1			
6·536	5·787	5·150	4·608	4·145	3·742	3·389	3·083	2·814	2·567	2·359	2·171	2·001	1·852	1·716	1·594	1·482	1·382	1·290	1·208	1·134	1·064	1				
6·145	5·441	4·843	4·333	3·898	3·519	3·187	2·898	2·646	2·413	2·218	2·042	1·882	1·741	1·614	1·499	1·394	1·300	1·212	1·136	1·066	1					
5·762	5·102	4·541	4·063	3·655	3·299	2·987	2·717	2·481	2·263	2·080	1·914	1·765	1·633	1·513	1·405	1·307	1·219	1·137	1·066	1						
5·406	4·787	4·261	3·812	3·430	3·096	2·804	2·550	2·328	2·123	1·952	1·796	1·656	1·532	1·420	1·318	1·226	1·144	1·067	1							
5·068	4·487	3·994	3·573	3·215	2·902	2·628	2·390	2·182	1·990	1·829	1·684	1·552	1·436	1·331	1·236	1·149	1·072	1								
4·726	4·184	3·725	3·332	2·998	2·706	2·451	2·229	2·035	1 856	1·706	1·570	1·447	1·339	1·241	1·152	1·072	1									
4·409	3·904	3·475	3·109	2·797	2·525	2·286	2·079	1·898	1·731	1·591	1·465	1·350	1·249	1·158	1·075	1										
4·100	3·631	3·232	2·891	2·601	2·348	2·126	1·934	1·766	1·610	1·480	1·363	1·256	1·162	1·077	1											
3·808	3·372	3·001	2·685	2·415	2·180	1·974	1·796	1·640	1·495	1·374	1·265	1·166	1·079	1												
3·528	3·124	2·781	2·488	2·238	2·020	1·830	1·664	1·519	1·386	1·274	1·172	1·081	1													
3·264	2·890	2·573	2·302	2·071	1·869	1·693	1·540	1·406	1·282	1·178	1·085	1														
3·009	2·664	2·372	2·122	1·909	1·723	1·560	1·419	1·296	1·182	1·086	1															
2·770	2·453	2·183	1·953	1·757	1·586	1·436	1·306	1·193	1·088	1																
2·546	2·255	2·007	1·795	1·615	1·458	1·320	1·201	1·096	1																	
2·322	2·056	1·830	1·637	1·473	1·330	1·204	1·095	1																		
2·120	1·877	1·671	1·495	1·345	1·214	1·099	1																			
1·929	1·708	1·520	1·360	1·223	1·104	1																				
1·746	1·546	1·376	1·231	1·108	1																					
1·576	1·395	1·242	1·110	1																						
1·418	1·255	1·117	1																							
1·268	1·123	1																								
1·129	1																									
1																										

TABLE VI.

TABLE OF PROPORTIONATE VALUES OF DISCHARGE, VELOCITY, AREA, WETTED PERIMETER, HYDRAULIC MEAN DEPTH AND $\sqrt{R}$ FOR CIRCULAR PIPES AT DIFFERENT DEPTHS OF FLOW.

(Values for full pipes taken as unity.)

Depth in terms of the Diameter.	Discharge in Cubic Feet per Minute. *Q.*	Velocity in Feet per Second *V.*	Area of Water Way in Square Feet *A.*	Wetted Perimeter in Feet *P.*	Hydraulic Mean Depth in Feet. *R.*	$\sqrt{R}$.
1·00	1·0000	1·0000	1·0000	1·0000	1·0000	1·0000
·99	1·0486	1·0504	·9983	·9362	1·0663	1·0318
·98	1·0661	1·0712	·9952	·9097	1·0940	1·0460
·97	1·0772	1·0867	·9913	·8892	1·1148	1·0558
·96	1·0844	1·0991	·9866	·8718	1·1316	1·0626
·95	1·0888	1·1096	·9813	·8564	1·1458	1·0704
·94	1·0911	1·1185	·9755	·8425	1·1579	1·0761
·93	1·0915	1·1261	·9692	·8295	1·1684	1·0809
·92	1·0903	1·1328	·9625	·8174	1·1775	1·0851
·91	1·0877	1·1385	·9554	·8060	1·1853	1·0887
·90	1·0839	1·1434	·9480	·7952	1·1921	1·0918
·89	1·0789	1·1477	·9401	·7848	1·1980	1·0945
·88	1·0730	1·1512	·9320	·7748	1·2029	1·0968
·87	1·0661	1·1542	·9236	·7652	1·2070	1·0987
·86	1·0582	1·1567	·9149	·7559	1·2104	1·1002
·85	1·0496	1·1586	·9059	·7468	1·2131	1·1014
·84	1·0403	1·1601	·8967	·7380	1·2150	1·1023
·83	1·0301	1·1610	·8873	·7294	1·2164	1·1029
·82	1·0193	1·1615	·8776	·7227	1·2171	1·1032
·81	1·0079	1·1616	·8677	·7129	1·2172	1·1033
·80	·9959	1·1612	·8576	·7048	1·2168	1·1031
·79	·9834	1·1605	·8473	·6969	1·2158	1·1026
·78	·9703	1·1595	·8369	·6892	1·2143	1·1019
·77	·9568	1·1580	·8262	·6816	1·2123	1·1010
·76	·9428	1·1562	·8154	·6741	1·2097	1·0999
·75	·9284	1·1540	·8045	·6667	1·2067	1·0985
·74	·9136	1·1515	·7934	·6594	1·2033	1·0969
·73	·8984	1·1487	·7822	·6522	1·1993	1·0951
·72	·8829	1·1455	·7708	·6450	1·1950	1·0931
·71	·8671	1·1420	·7593	·6380	1·1902	1·0909
·70	·8510	1·1382	·7477	·6310	1·1849	1·0885
·69	·8346	1·1341	·7360	·6241	1·1793	1·0859
·68	·8180	1·1296	·7241	·6172	1·1732	1·0831
·67	·8012	1·1249	·7122	·6104	1·1667	1·0801
·66	·7841	1·1199	·7002	·6037	1·1599	1·0770
·65	·7669	1·1145	·6881	·5970	1·1526	1·0736
·64	·7495	1·1089	·6759	·5903	1·1449	1·0700
·63	·7319	1·1029	·6636	·5838	1·1368	1·0662
·62	·7144	1·0968	·6513	·5771	1·1285	1·0623
·61	·6966	1·0903	·6389	·5706	1·1197	1·0581
·60	·6788	1·0835	·6265	·5641	1·1106	1·0538
·59	·6609	1·0764	·6140	·5576	1·1011	1·0493
·58	·6430	1·0691	·6014	·5511	1·0912	1·0446
·57	·6250	1·0614	·5888	·5447	1·0810	1·0397
·56	·6071	1·0535	·5762	·5383	1·0704	1·0346
·55	·5891	1·0453	·5636	·5319	1·0595	1·0293
·54	·5712	1·0368	·5509	·5255	1·0483	1·0239
·53	·5533	1·0280	·5382	·5191	1·0367	1·0182
·52	·5354	1·0190	·5255	·5127	1·0248	1·0123
·51	·5177	1·0096	·5127	·5064	1·0126	1·0063

TABLE OF PROPORTIONATE VALUES OF DISCHARGE, VELOCITY, AREA, WETTED PERIMETER, HYDRAULIC MEAN DEPTH AND $\sqrt{R}$ FOR CIRCULAR PIPES AT DIFFERENT DEPTHS OF FLOW—*continued.*

(Values for full pipes taken as unity.)

Depth in terms of the Diameter.	Discharge in Cubic Feet per Minute. *Q.*	Velocity in Feet per Second *V.*	Area of Water Way in Square Feet *A.*	Wetted Perimeter in Feet *P.*	Hydraulic Mean Depth in Feet. *R.*	$\sqrt{R}$.
·50	·5000	1·0000	·5000	·5000	1·0000	1·0000
·49	·4824	·9901	·4873	·4936	·9871	·9935
·48	·4650	·9799	·4745	·4873	·9739	·9869
·47	·4477	·9694	·4618	·4809	·9604	·9800
·46	·4305	·9586	·4491	·4745	·9465	·9729
·45	·4135	·9475	·4364	·4681	·9323	·9656
·44	·3967	·9361	·4238	·4617	·9179	·9581
·43	·3801	·9244	·4112	·4553	·9031	·9503
·42	·3637	·9124	·3986	·4488	·8880	·9423
·41	·3475	·9001	·3860	·4424	·8726	·9341
·40	·3315	·8875	·3735	·4359	·8569	·9257
·39	·3158	·8746	·3611	·4294	·8409	·9170
·38	·3003	·8613	·3487	·4229	·8246	·9081
·37	·2852	·8478	·3364	·4163	·8080	·8989
·36	·2702	·8338	·3241	·4097	·7911	·8895
·35	·2557	·8197	·3119	·4030	·7740	·8798
·34	·2414	·8051	·2998	·3963	·7565	·8698
·33	·2274	·7902	·2878	·3896	·7387	·8595
·32	·2138	·7750	·2759	·3828	·7224	·8499
·31	·2005	·7594	·2640	·3759	·7024	·8381
·30	·1876	·7434	·2523	·3690	·6838	·8269
·29	·1750	·7271	·2407	·3620	·6649	·8154
·28	·1628	·7104	·2292	·3550	·6457	·8036
·27	·1510	·6933	·2178	·3478	·6262	·7914
·26	·1396	·6758	·2066	·3406	·6065	·7788
·25	·1286	·6580	·1955	·3333	·5865	·7658
·24	·1180	·6397	·1845	·3259	·5662	·7525
·23	·1079	·6209	·1738	·3184	·5457	·7387
·22	·0982	·6017	·1631	·3108	·5248	·7245
·21	·0889	·5821	·1527	·3031	·5037	·7097
·20	·0801	·5625	·1424	·2952	·4824	·6945
·19	·0700	·5414	·1323	·2871	·4607	·6788
·18	·0637	·5203	·1224	·2789	·4388	·6624
·17	·0561	·4986	·1127	·2706	·4167	·6455
·16	·0492	·4764	·1033	·2620	·3942	·6279
·15	·0427	·4537	·0941	·2532	·3715	·6095
·14	·0366	·4303	·0851	·2441	·3485	·5904
·13	·0310	·4063	·0764	·2348	·3253	·5704
·12	·0259	·3816	·0680	·2252	·3018	·5494
·11	·0213	·3562	·0598	·2152	·2781	·5286
·10	·0172	·3300	·0520	·2048	·2541	·5041
·09	·0135	·3030	·0446	·1940	·2298	·4794
·08	·0103	·2751	·0375	·1826	·2053	·4531
·07	·0076	·2462	·0308	·1705	·1805	·4249
·06	·0053	·2162	·0251	·1575	·1555	·3943
·05	·0035	·1851	·0187	·1436	·1302	·3608
·04	·0020	·1525	·0134	·1282	·1047	·3235
·03	·0010	·1184	·0087	·1108	·0789	·2809
·02	·0004	·0822	·0048	·0903	·0528	·2299
·01	·00007	·0434	·0017	·0638	·0265	·1629

Butler & Tanner, The Selwood Printing Works, Frome, and London.

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